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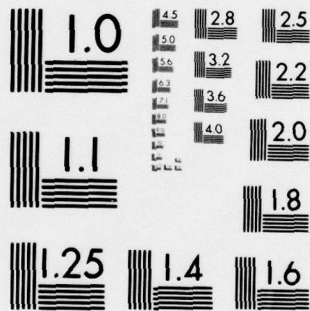
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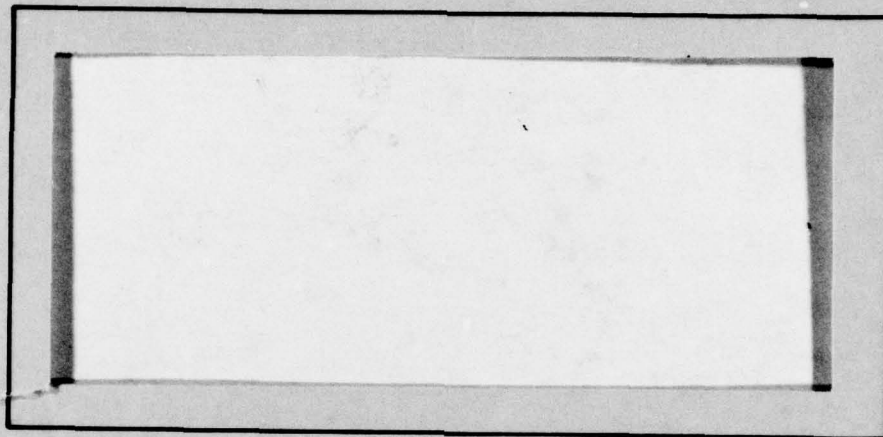


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SATELLITE MEASUREMENTS OF TROPOSPHERIC AEROSOLS.

Presented at
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ABSTRACT

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Landsat data were originally used to demonstrate that a linear relationship exists between the upwelling visible radiance and the aerosol optical thickness (essentially all of this thickness is in the troposphere) over oceans. Since that time similar relationships have been shown to exist for sensors on the GOES and NOAA-5 satellites. A global scale ground truth experiment using Tiros-N data is planned and will investigate the variability of the linear relationship at different sites around the globe. A comparison of the results for the different satellites is presented, together with a discussion of the requirements for routine satellite monitoring of tropospheric aerosols on a global scale. ↗

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1. INTRODUCTION

The use of satellite radiance measurements to determine the atmospheric aerosol optical thickness has been under investigation for several years.^{1,2,3} It has been shown that, over ocean surfaces, a linear relationship exists between the upwelling radiance in the visible regions and the aerosol content. The aerosol content is defined in terms of the Elterman⁴ model vertical aerosol optical thickness; i.e., the aerosol content is given by the ratio (measured aerosol optical thickness at wavelength λ to a model aerosol optical thickness at wavelength λ) $\times N$; i.e., a value of $2N$ for the aerosol content indicates that the optical thickness is twice that of the Elterman model. In the results reported here, measurements of the aerosol optical thickness were available only at $0.5 \mu\text{m}$, so that all radiances measured by the different radiometers are plotted against aerosol content where N indicates an aerosol optical thickness of 0.213 (the Elterman model value) measured at $0.5 \mu\text{m}$.

Linear relationships between the upwelling radiance and the aerosol content have been determined for Landsat 1¹, Landsat 2², NOAA-5³, and GOES-1³. A global scale ground truth experiment using Tiros-N data is planned and will investigate the variability of the linear relationship at different sites around the globe.

2. LANDSAT RESULTS

Data have been obtained at several sites for Landsat overpasses⁵, the largest data set being for the Pacific Ocean at San Diego for Landsat 2 overpasses. These results are shown in Figure 1. The radiances are determined from the Landsat digital data (densitometry of the black and white imagery is not accurate enough for intercomparison of different images), and the aerosol content values are determined with ground-based Volz sun photometer measurements at the time of the Landsat overpass. The radiance values are for nadir viewing, and radiances are based on the theoretical variation of upwelling radiance with sun angle, calculated with the Dave⁶ atmospheric scattering code.

The relationships appear best for multispectral scanner (MSS) channels MSS 5 and MSS 6; this is probably due to the fact that the radiance in MSS 4 is affected by suspended matter in the water. Figure 1 does not show MSS 7 data, since the digital data for this channel are uncertain owing to NASA procedures for producing Landsat 2 computer compatible tapes.

3. GOES RESULTS

The Naval Research Laboratory conducted an Electro-Optical Meteorology (EOMET) cruise across the North Atlantic Ocean in May 1977. Arrangements were made for sun photometer measurements of the atmospheric aerosol optical thickness to be taken daily, weather permitting, on board the U.S.N.S. Hayes (EOMET cruise vessel) at times as nearly coincident as possible with the overpasses of NOAA-5 (0800-1000 local standard time) and at 1600 GMT, when GOES-1 digital data are routinely recorded and stored.

The results for the GOES-1 measurements are shown in Figure 2. These radiances have been normalized to the Landsat viewing and sun angle conditions using the Dave code.

In December 1978, two more data points were obtained for GOES-1 just off the coast from Panama City, Florida. The results shown in Figure 2 show very good agreement with the Atlantic data obtained nineteen months earlier.

In May 1978, five sets of data were obtained at San Nicholas Island on five days for SMS-2, the same type of satellite as GOES-1, but positioned over the Pacific Ocean. Unfortunately, the aerosol content was essentially the same each day, so that the linear relationship could not be investigated. However, the satellite did measure essentially the same radiance each time, thus verifying the repeatability of the technique. The data points are represented in Figure 2 by a single circle which would enclose all five points.

4. NOAA-5 RESULTS

The NOAA-5 Scanning Radiometer (SR) data were obtained in digital form from the National Environmental Satellite Service (NESS) of NOAA. The SR data were available only in the mapped format (with 20 km resolution) for this investigation, and did not provide all the resolution elements actually measured during the satellite overpasses. Another shortcoming of the SR data is the fact that the SR output is subject to a non-random noise which cannot be readily eliminated. In an attempt to minimize these effects, each SR radiance reported here is the mean of 5×5 block of pixels centered on the calculated ship location.

However, in spite of these shortcomings, the relationship shown for the SR radiances in Figure 3 is remarkably good. A linear relationship can probably be inferred. The crosses show an enhanced radiance due to sun-glitter, and demonstrate that observations should be made away from the sun, except close to the nadir as illustrated by the circle.

5. COMPARISON OF RESULTS

The radiance-aerosol content relationships are found to be different for each satellite, even when the differences in spectral response are accounted for. For example, it is found that for the SR data, the radiance value for $N = 0$ is as expected (this value is independent of the aerosol properties, and represents a pure molecular atmosphere), but that the other radiances are lower than expected. This can be due to the aerosol properties being different from those of the Landsat San Diego data, or can be due to uncertainties in the radiometric calibrations in each satellite. However, in the Landsat Study⁵, data obtained at Adrigole, Ireland, for Atlantic Ocean aerosols showed good agreement with the San Diego data. The same study showed that differences also existed between the Landsat 1 and Landsat 2 results at San Diego, and it was concluded that they were due to differences in the radiometric calibrations of the two satellites. It is believed that similar calibration problems are responsible for the SR and Landsat differences. Indeed, in examining the GOES results in Figure 2, it is found that both the intercept and slope of the line are significantly different from those predicted from the Landsat data, suggesting again that the reason is due to the radiometric calibrations.

6. PLANNED TIROS-N EXPERIMENT

In order to determine utility of this technique for measuring aerosols on a global scale, it is necessary to determine the variability of the radiance-aerosol content relationship at different locations. As discussed above, the uncertainties in the radiometric calibrations of different satellites prevent any conclusions presently being reached on aerosol properties. In the summer of 1979, the global variation of a three month ground truth program using a single satellite, Tiros-N (NOAA-6), will take place. In this experiment, the sun photometer measurements will be made daily at twelve ocean sites around the globe. The results at the different sites should provide answers about the global variability of the radiance-aerosol content relationship without being concerned with the satellite radiometric calibration, assuming it does not change during the three month period.

7. REQUIREMENTS FOR GLOBAL MONITORING

Assuming that little global variation of the radiance-aerosol content relationship is found, or that different relationships can be used to characterize different regions, then measurements of the aerosol content can be made globally over oceans on a routine basis. A table look up algorithm has already been developed to readily convert radiance to aerosol content, given the viewing and sun angles. Of course, regions of cloud cover and sun glint must be avoided. A method of screening out obvious clouds from the data already exists in the production of sea surface temperature maps; however, it is possible that thin cirrus clouds could be confused with aerosols. Sun glint can be avoided simply by considering only radiances obtained when the sensor is pointed away from the sun.

The possibility⁵ of extending the ocean measurements over landmasses, by using inland bodies of water such as rivers, lakes and reservoirs, is currently being pursued. For inland bodies of water, which generally exhibit signs of water turbidity, and hence a larger than usual reflectivity in the visible spectrum, it is proposed to use the upwelling radiance in the near infrared ($\sim 0.9 \mu\text{m}$) region. This radiation has not significantly penetrated the water, and hence is not influenced by the suspended matter in the water as much as in the visible region.

8. CONCLUSIONS

A linear relationship between the upwelling visible radiance, as observed by the Landsat MSS, and the atmospheric aerosol content, has also been found for the GOES and the NOAA-5 sensors. The relationships are slightly different for each satellite. These differences are attributed to differences in the radiometric calibrations of the satellites, and point to the necessity of precise radiometric calibrations of satellite radiometers if they are to be used in the future for aerosol measurements. Without precise calibration each satellite would have to be empirically calibrated with lengthy periods of ground truth measurements. The planned Tiros-N ground truth experiment will provide information on the global variability of aerosol properties, and will hopefully lead to routine satellite monitoring of aerosols on a global basis.

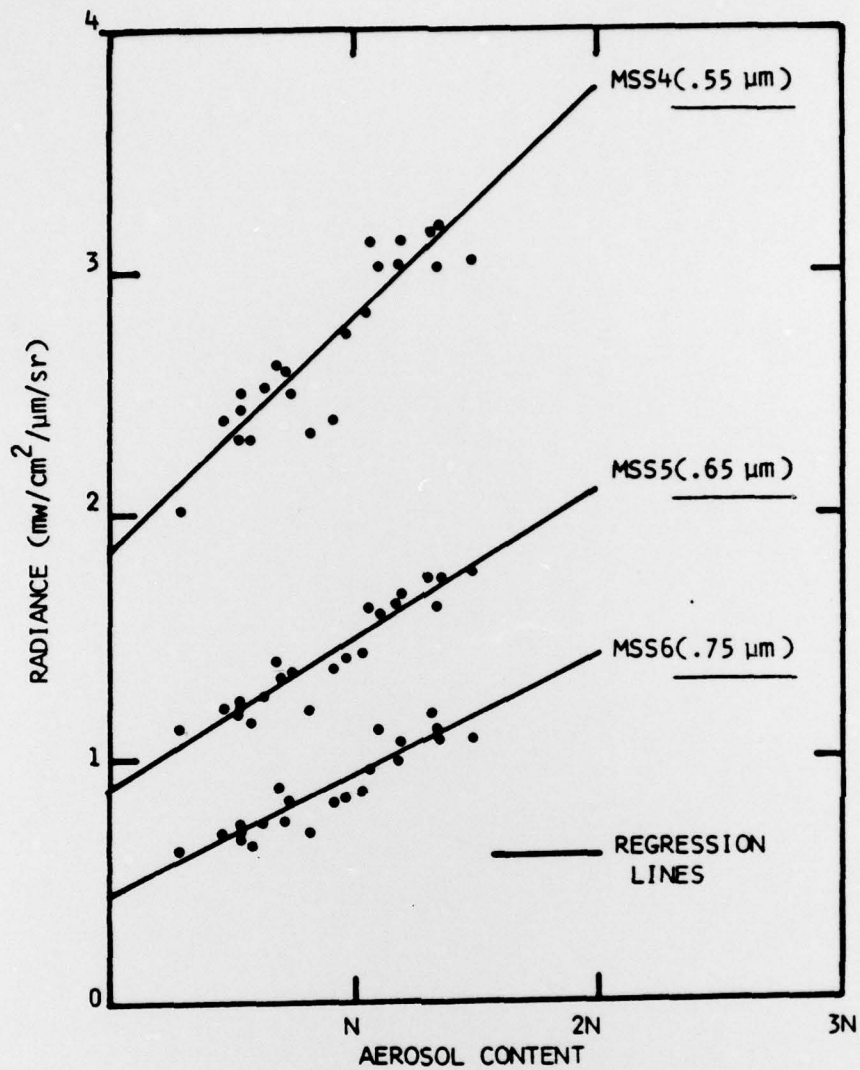


Figure 1. Landsat 2 ocean radiances versus aerosol content. The radiances are for nadir viewing normalized to a sun zenith angle of 63°.

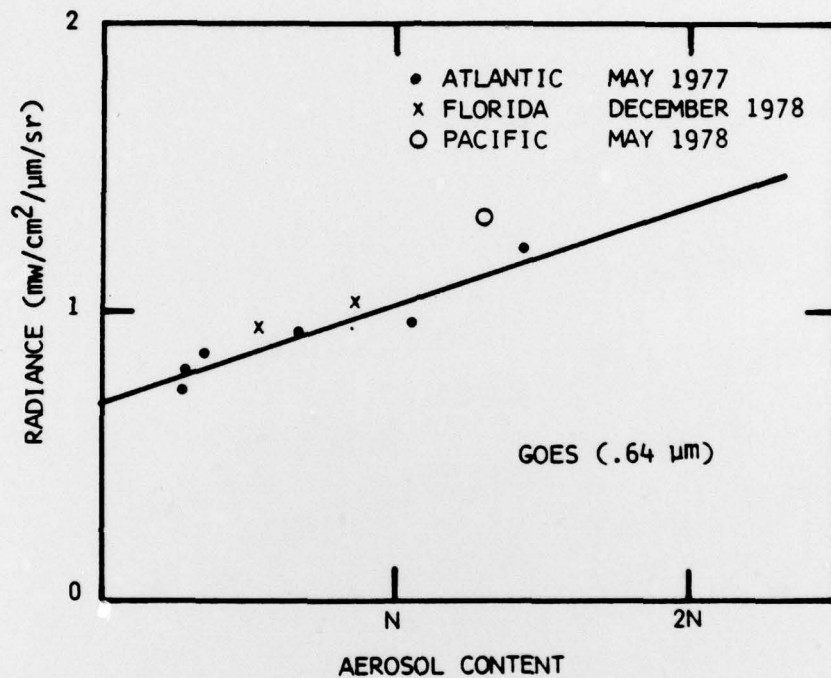


Figure 2. GOES ocean radiances versus aerosol content. The radiances are normalized to nadir viewing with a sun zenith angle of 63° .

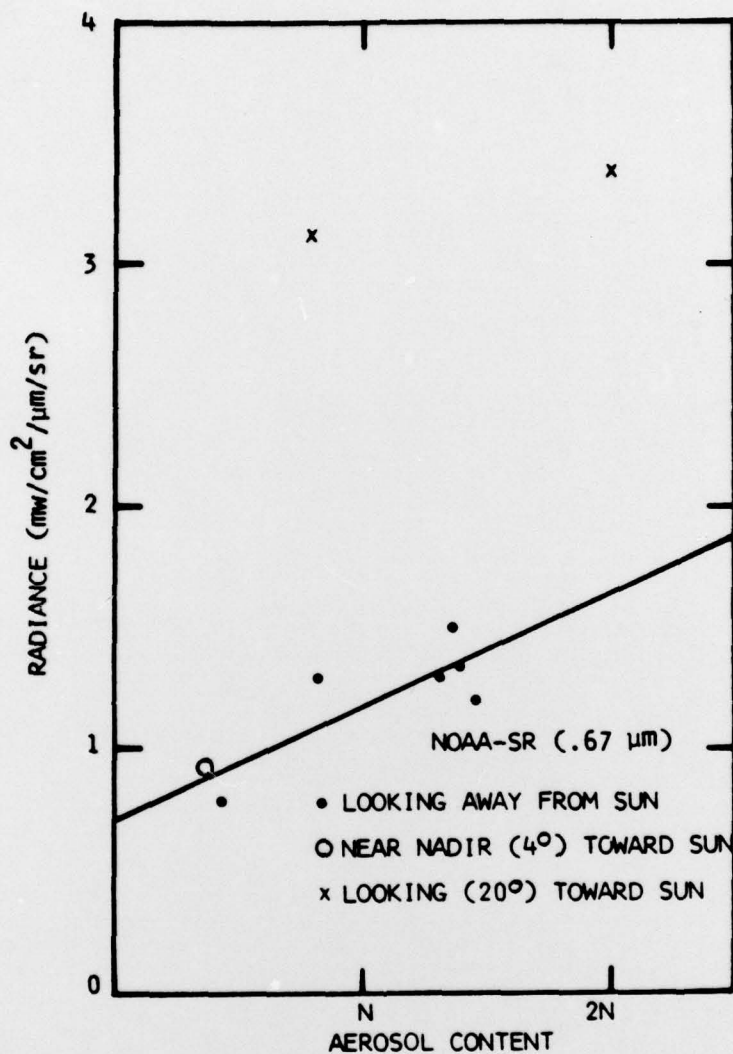


Figure 3. NOAA-5 ocean radiances versus aerosol content. The radiances are normalized to nadir viewing with a sun zenith angle of 63°.

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